Local dynamic similarity concept as applied to evaluation of discharge coefficients of cross-ventilated buildings. Part 2: Applicability of local dynamic similarity concept

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ABSTRACT

In order to perform detailed evaluation on the applicability of local dynamic similarity concept, which is described in Part 1, wind tunnel experiment was conducted under some conditions where the opening positions and the arrangement of buildings were changed in more complicated manner.

As a result, it has been found that the discharge coefficient C_d can be predicted accurately from P_R* for the most of opening positions, even if the approaching flow angle is varied or another building is standing near the opening. It has been also found that there are no substantial problems for predicting C_d from P_R* when the direction of interfering crossflow is changed or there is wall/floor near the opening as disturbing the diffusion of incoming airflow. However, it should be known that the prediction accuracy of C_d is lowered when these conditions simultaneously occur.

1. INTRODUCTION

Natural ventilation is an energy-efficient technology that is adopted to reduce energy consumption for cooling of buildings. In order to effectively promote the utilization of cross-ventilation, it is important to establish a high-precision model for predicting ventilation flow rate as a basic technique.

Today, the following orifice equation is generally used for the estimation of flow rate (Q) in natural ventilation:

$$Q = C_d A \sqrt{\frac{2}{\rho}\left(P_W - P_R\right)} \tag{1}$$

where C_d is discharge coefficient, A is opening area, P_R is room pressure, and P_W is wind pressure.

However, the value of C_d is changed depending on incident angle of approach flow or opening position. Therefore, it is difficult to accurately estimate ventilation flow rate from the above equation. In this respect, we tried to explain the change of discharge coefficient by introducing the local dynamic similarity concept in Part 1 (Kurabuchi et al., 2005). Thus, P_R*, which is the index to uniquely determine the discharge coefficient, was defined as follows:

$$P_R{}^* = \frac{P_R - P_W}{P_t} = \frac{P_R - P_W}{P_T - P_W} \tag{2}$$

where P_t is dynamic pressure tangential to the wall (interfering crossflow dynamic pressure) at the opening, and P_T is total pressure at the opening (Fig. 1).

In Part 2, from the viewpoint of the application to actual building, wind tunnel experiment was carried out under some extended conditions where opening position and building position were changed in more complicated manner, and the application range of the local similarity concept was investigated.

2. METHODS

The experiment was carried out by using the

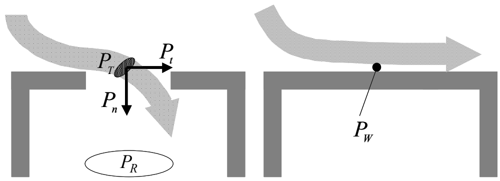


Figure 1: Definition of pressure around opening.

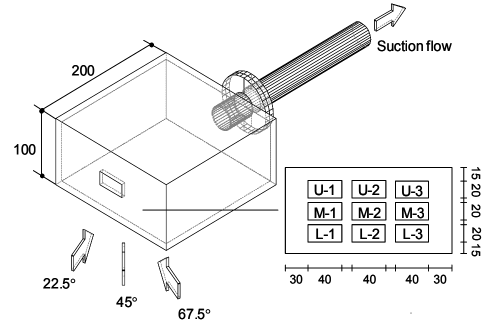


Figure 2: Suction type ventilation model and opening positions (scale:mm).

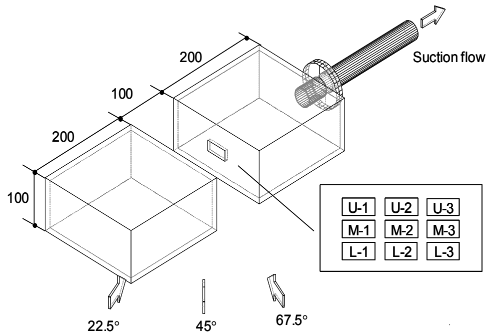


Figure 3: Arrangement of adjacent building models.

Eiffel type of wind tunnel at Tokyo Polytechnic University and the building model as shown in Figure 2.

In the present experiment, the opening position was widely changed when compared to Part 1. As shown in Figure 2, nine opening positions were designed, and three opening positions were located at the different height on the wall. To test on more complicated conditions, another building model was placed on the windward side of the building model as shown in Figure 3, and an experiment on the same opening positions was also performed. The opening position was changed by replacing the panel on the windward side of the building model.

As already described in Part 1, for the purpose of simulating various ventilation flow rate, a hose was connected on the leeward side of the model, and the ventilation flow rate was controlled by a suction fan installed outside the wind tunnel. The ventilation flow rate was measured by a thermal flow meter mounted on the middle of the hose. Methods of P_T, P_W and P_R measurements and profile of approach flow were described in Part 1. In the present experiment, the incident angle of approach flow was set to 22.5°, 45°, and 67.5°.

3. RESULTS AND DISCUSSIONS

First of all, C_d was measured under the stagnant condition without approach flow, where $|P_R^*|$ was considered to be infinity. It was found that the value was distributed between 0.64 and 0.67 and was almost constant as shown in Figure 4.

Then, the relation between P_R^* and C_d were observed at each opening position and each incident angle of approach flow with changing the ventilation flow rate. The relation was shown in Figures 4, 5 and 6, for each height of the opening positions. In these figures, a basic line is also depicted, which indicates the relation between P_R^* and C_d at the basic opening position M-2. Figure 5 shows that the relation between P_R^* and C_d at the openings of the middle height is the same as in the basic line. At the upper openings, the value of C_d was also consistent with the basic

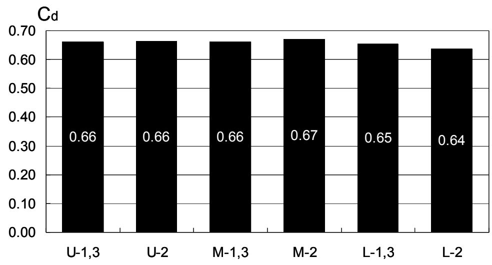


Figure 4: Discharge coefficients (C_d) in case of $|P_R^*|=\infty$.

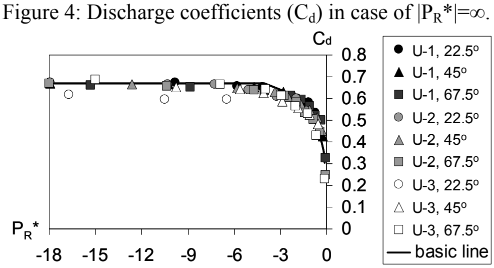


Figure 5: Relations between P_R^* and C_d at upper openings.

line, although C_d of U-3 was a little lower when the incident angle was 22.5°. However, the C_d corresponding to $|P_R^*|$ tend to be smaller at the lower openings than that of the basic line. It was more obvious in the opening position on the windward side.

Next, the results of the experiment are shown in Figures 8, 9 and 10 when another building model was placed on the windward side of the building model. As shown in these figures, the relation between P_R^* and C_d at the upper and middle openings was almost consistent with the basic line, while the C_d corresponding to $|P_R^*|$ tend to be smaller at the lower openings than that of the basic line. These were the same findings as in the case of isolated building model.

The results of the experiment as described above confirms that it is possible to evaluate C_d by using P_R^* as an index for most of opening positions even if another building is standing in front of the opening.

On the other hand, when the opening was located on the lower part of the wall, the C_d corresponding to $|P_R^*|$ tend to be smaller than that of the basic line.

It might be attributed to that the direction of the interfering crossflow on the lower area of the wall was not parallel to the floor. That was probably diagonal to downward, while the direction of the interfering crossflow on the other area was primarily parallel to the floor.

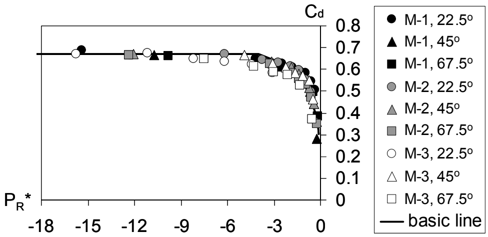


Figure 6: Relations between P_R^* and C_d at middle openings.

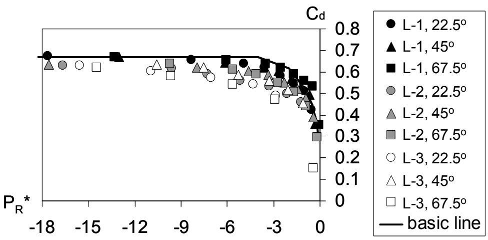


Figure 7: Relations between P_R^* and C_d at lower openings.

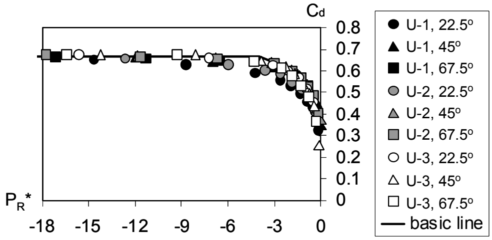


Figure 8: Relations between P_R^* and C_d at upper openings faced toward another building.

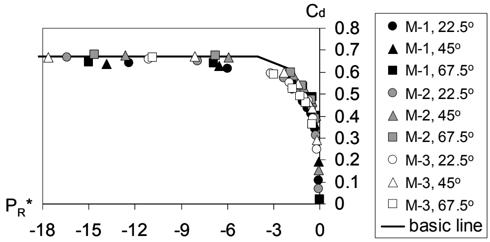


Figure 9: Relations between P_R^* and C_d at middle openings faced toward another building.

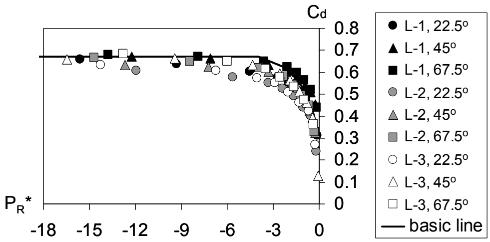


Figure 10: Relations between P_R^* and C_d at lower openings faced toward another building.

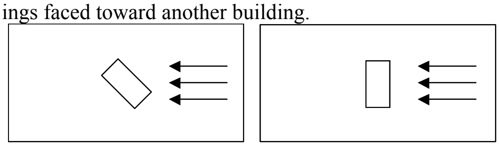


Figure 11: Rotated openings (left: 45°, right: 90°).

In order to confirm this, an additional experiment was done, and the opening at the basic position of M-2 was rotated as shown in Figure 11. As a result, it was found that the direction of the interfering crossflow influences upon the relation between P_R^* and C_d as shown in Figure 12.

However, as shown in Figure 7 or Figure 10, C_d is rather lower than the case where the opening was rotated at an angle of 90°. Therefore, another influence of the floor and wall, which disturb the diffusion of the incoming flow in the room, was also tested. For this test, partition wall or double floor was installed in the building model. The partition wall was located on the leeward side or windward side of the basic opening M-2, and the double floor was provided on the lower end of the opening as shown in Figure 13.

Figure 14 shows C_d with inside wall or floor when the value of $|P_R*|$ is infinity. It was lower than that without inside wall or floor, but the difference was only 0.04. As shown in Figure 15, C_d tends to be lower than the basic line under all

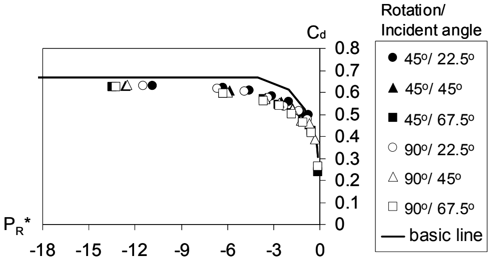
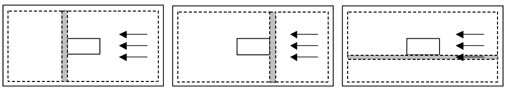


Figure 12: Relations between P_R* and C_d at rotated openings.



(a) Wall-1 (b) Wall-2 (c) Double floor

Figure 13: Partition wall and double floor inside building model.

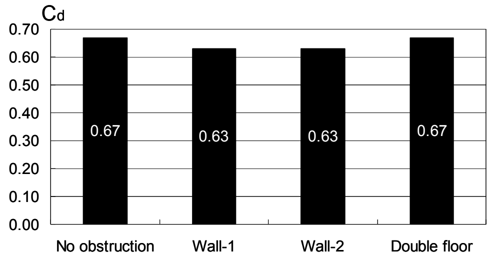


Figure 14: Discharge coefficients (C_d) of openings with partition wall or double floor in case of $|P_R*|=\infty$.

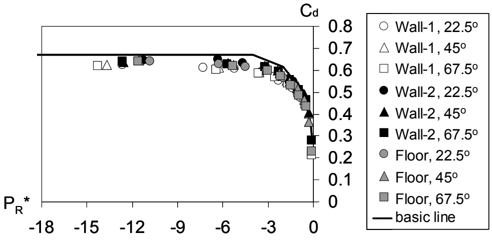


Figure 15: Relations between P_R* and C_d at openings with partition wall or double floor.

conditions. And that is most obviously when the wall was installed on the leeward side, i.e. when the wall was standing against the incoming air-flow.

As shown in Figures 12 and 15, the difference of C_d from the basic line was only up to 0.1 under those conditions. Thus, it would not be substantial problem when we apply the present concept in practice to those conditions. However, it should be known that the prediction accuracy of C_d is lowered when these conditions simultaneously occur such as the openings on the lower part of wall in this study.

5. CONCLUSIONS

The present study are concluded as follows:

- Discharge coefficient C_d could be predicted accurately from P_R* for the most of opening positions, even if the approaching flow angle is varied or another building is standing near the opening.
- Under the condition where the direction of interfering crossflow was varied or there is any inside wall/floor disturbing diffusion of incoming flow, the C_d corresponding to $|P_R*|$ tends to be slightly smaller than that in the basic relation.
- Those conditions respectively cause no substantial problem for predicting C_d from P_R*. However, it should be known that the prediction accuracy of C_d is lowered when those conditions occur simultaneously.

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NOTATION

- A: opening area,
- C_d: discharge coefficient,
- Q: ventilation flow rate,
- P_n: dynamic pressure normal to wall,
- P_R: room pressure,
- P_t: dynamic pressure tangential to wall,
- P_T: total pressure,
- P_W: wind pressure.